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Centaur for the 1980's

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CENTAUR FOR THE 1980s

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ABSTRACT

Centaur is currently the world's only operational high-energy upper stage, and is the United States primary upper stage for launching solar system probes, large geosynchronous communication satellites, and observatories to study the farthest limits of space. Centaur is currently launched on Atlas, but has also flown with the larger Titan booster. NASA recently decided to integrate Centaur with the Space Shuttle for future solar system exploration missions.

Current status of the Centaur program is discussed including: vehicle characteristics, planned performance improvements, and launch schedules. Modifications required to integrate Centaur with Shuttle and the resulting capabilities are discussed.

INTRODUCTION

Centaur development began in 1958 when General Dynamics/Convair was awarded a contract to develop the first space vehicle to use liquid hydrogen fuel. Because NASA's Lewis Research Center (LeRC) did much of the pioneering work in liquid hydrogen technology, LeRC was later assigned technical management of Centaur and contributed to the first successful launch in 1963. This successful working relationship continues today. After completing the development phase in 1966, the resulting operational vehicle, called Centaur D, was launched 21 times on Atlas.

In the early 1970s, Centaur electronics and guidance systems were completely modernized. A new high-speed digital computer was added that permits extensive use of software to perform functions previously requiring hardware, thus simplifying new mission adaptation. Computer controlled launch set (CCLS) was added to provide rapid automatic checkout of the Centaur and diagnostic capabilities for anomalies. This new version of Centaur, designated D-1, was integrated with both the Atlas vehicle and the more powerful Titan booster, and has flown 32 operational missions.

Currently, Centaur is undergoing additional performance improvements for Intelsat, which will enhance its capabilities for the 1980s. NASA has also recently decided to integrate Centaur with the Space Shuttle for solar exploration missions, large future geosynchronous commercial satellites, and potential Department of Defense (DoD) missions. These applications will ensure continued use of Centaur through the remainder of the 1980s.

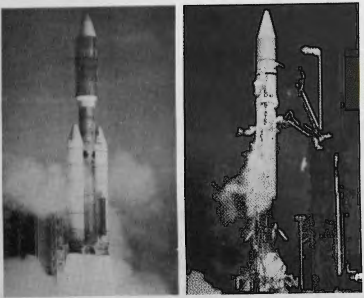
CENTAUR RECORD

A little over two decades ago, Centaur was conceived as the upper stage for United States' solar system exploration and geosynchronous communications satellites. Today that dream has truly been fulfilled by the accomplishments of this vehicle. Centaur has launched 22 solar system exploration missions including Voyager, Viking, Helios, Mariner, Surveyor and Pioneer. Its selection by NASA for launching the Galileo and International Solar Polar missions from Space Shuttle means continuation of this enviable record. In addition, 24 geosynchronous communication satellites have been launched as well as 6 space observatories (Figure 1). Centaur has flown 55 times with Atlas and 7 times on Titan for a total of 62 flights and is now ready for integration with the Space Shuttle.

During the past fifteen years of operational flights, Centaur has established itself as a reliable upper stage. 96% of all operational flights were successful, with 100% or 36 consecutive successes since 1971. The Pratt and Whitney RL-10 engines have a perfect flight success record and the current Centaur D-1 guidance and navigation system has also performed 100% successfully on all countdowns and launches as indicated in Figure 2.

ATLAS CHARACTERISTICS

The Atlas vehicle that boosts Centaur is a stage-and-a-half configuration in which all engines are ignited on



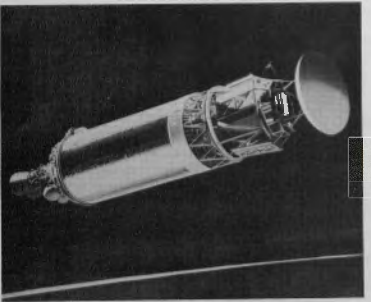
Missions

- Solar system exploration (22)
  - Voyager, Viking, Helios
  - Mariner, Pioneer, Surveyor
- Communications (25)
  - Intelsat, Fltsatcom, Comstar
- Astronomy (6)
  - HEAO, OAO

Launch platforms

- Atlas
- Titan

Figure 1. Centaur enabled the United States to achieve many dramatic firsts in space and provided a valuable capability for geosynchronous missions.



Vehicle operational successes

— 96% overall
— 100% since 1971
(36 consecutive successes)

P&W RL-10 engine

— 100% successful flight record
(66,000 sec in space)

Guidance & Navigation — D-1

(Honeywell IRU & Teledyne DCU)
— 100% flight & countdown success
(33 missions with 450 operational hours)

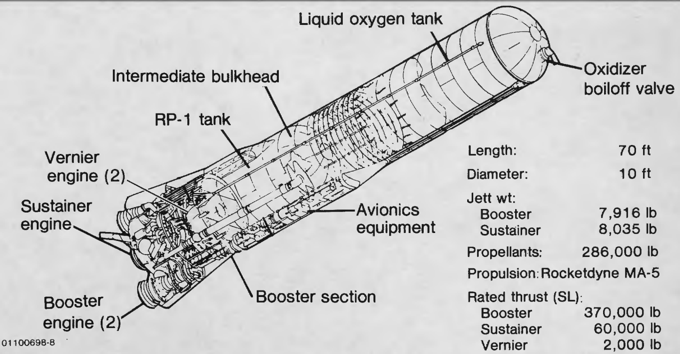
Figure 2. Centaur's success record proves its reliabilty as a high-energy upper stage.

the ground and share common propellant tanks. The booster engines are jettisoned at approximately 140 seconds into the flight when vehicle acceleration reaches 5.5 g. The sustainer engine continues to burn until propellant depletion occurs about 110 seconds later. Two small vernier engines burn throughout the booster phase and provide all roll control during the sustainer phase. All engines use liquid oxygen (LO_2) and RP-1 fuel, which is similar to kerosene. Vehicle characteristics are shown in Figure 3.

The Atlas vehicle is 10 ft in diameter and approximately 70 ft in length, not including the interstage adapter. Tanks are made of thin-walled stainless steel bands which are welded together and pressure stabilized for structural strength. A helium pressurization system maintains tank pressure for structural integrity and turbopump pressure head during flight. Vehicle control is accomplished by gimbaling the Atlas engines during flight under direction of the Centaur guidance and navigation system.

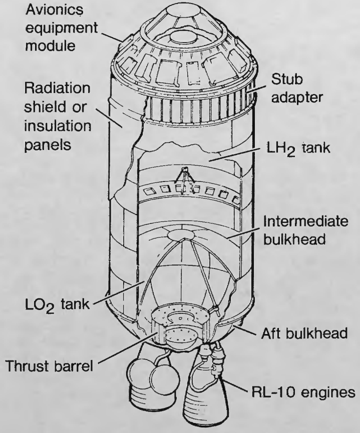
CENTAUR CHARACTERISTICS

Centaur is a high energy upper stage powered by two Pratt & Whitney RL-10 engines developing 33,000 lb total vacuum thrust at a rated Isp of 446 seconds (see Figure 4). The stage burns 30,000 lb of liquid hydrogen (LH_2) and liquid oxygen (LO_2) propellants. Tanks are made of thin-walled type 301 stainless steel welded construction that is pressure stabilized. They are separated by a double-wall vacuum-insulated intermediate common bulkhead and pressurized with gaseous helium. Until now, tank-mounted boost pumps have been used to provide the required engine inlet pressures. The boost pumps are driven by turbines



Length:	70 ft
Diameter:	10 ft
Jett wt:	
Booster	7,916 lb
Sustainer	8,035 lb
Propellants:	286,000 lb
Propulsion:	Rocketdyne MA-5
Rated thrust (SL):	
Booster	370,000 lb
Sustainer	60,000 lb
Vernier	2,000 lb

Figure 3. The Atlas booster vehicle is a state-and-a-half configuration with a sustainer engine that continues to burn 90 seconds after the initial booster engines are jettisoned.



Length:	30 ft
Diameter:	10 ft
Dry weight:	3,850 lb
Guidance:	Inertial
Propulsion:	P&W RL-10A-3-3
Rated Thrust:	16,500 lb per engine
Rated I_{sp} (vac):	446 sec
Propellants:	LO_2/LH_2; 30,750 lb

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Figure 4. Centaur characteristics.

powered by hydrogen peroxide, the same monopropellant used in the reaction control system. Beginning with vehicle AC-62, minor tank and engine changes have allowed the elimination of boost pumps. Reduced cost and improved reliability and performance will result. Associated changes are gaseous hydrogen engine bleed for LH_2 tank pressurization during engine operation, and hydrazine monopropellant for the reaction control system.

The Centaur integrated astrionics system is illustrated in Figure 5. The heart of this system is the Teledyne Digital Computer Unit (DCU) which has 16,000

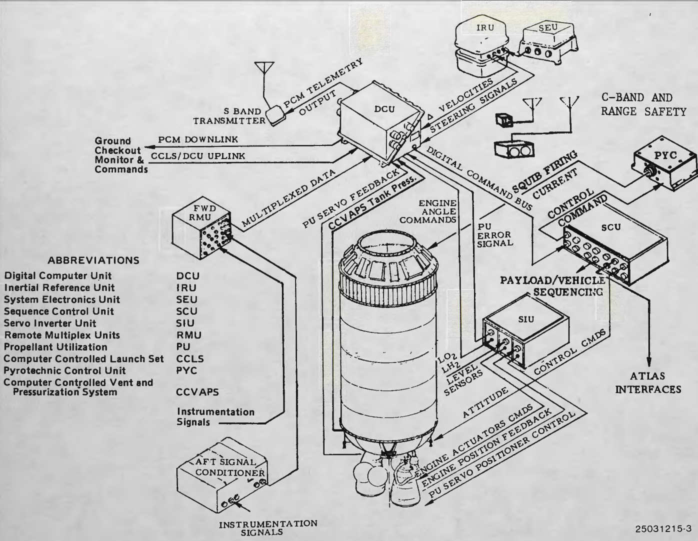


Figure 5. Centaur astrionics system.

words of memory, fast execution speed, and extensive input-output capabilities allowing it to perform many functions that previously required separate hardware.

A Honeywell Inertial Reference Unit (IRU) containing four-gimbals, three reference gyros, and three pulse-balanced accelerometers provides the required navigation data for the DCU. The DCU generates output commands to provide vehicle stability and guidance steering that are routed through the servo inverter unit (SIU) during powered flight and through the sequence control unit (SCU) during coast phase. Centaur flight software is modularized into several special-purpose subroutines that are operated in real time by an executive program. This allows the DCU to provide total vehicle command and control including: tank pressurization and vent management, dynamic stability, sequencing, propellant consumption management, telemetry formatting, and pre-flight testing, as well as guidance and navigation functions.

PERFORMANCE IMPROVEMENTS

A number of performance improvements have been incorporated into Atlas/Centaur in order to meet increasing Intelsat V requirements without spacecraft apogee kick motor changes. These included an engine thrust increase (1,500 lb/eng), a zero-gravity parking orbit coast, earlier nose fairing jettison, and weight improvements. Additional changes are being incorporated to the Atlas/Centaur for the first Intelsat VA launch. These changes include adding a silver throat to the Centaur engine (+2.4 sec Isp), deleting the boost pumps, and using hydrazine for reaction control. The resulting capability for synchronous transfer is shown in Figure 6, and indicates a payload system weight capability of 4,900 lb for a near optimum transfer. Recently, the Intelsat Board approved an 80-inch Atlas stretch for the 1984 launches that will increase the Atlas/Centaur peformance capability to 5,300 lb.

Additional performance growth could be available as shown in Figure 7, by adding four Castor IV solid propellant motors and igniting two on the ground and two at altitude after the first two burnout. These are the same motors currently used with Delta and would result in a synchronous transfer capability for launching two full size Delta class 2,800 lb spacecraft on a single Atlas/Centaur using a Centaur tandem adapter (CTA) as indicated in Figure 8.

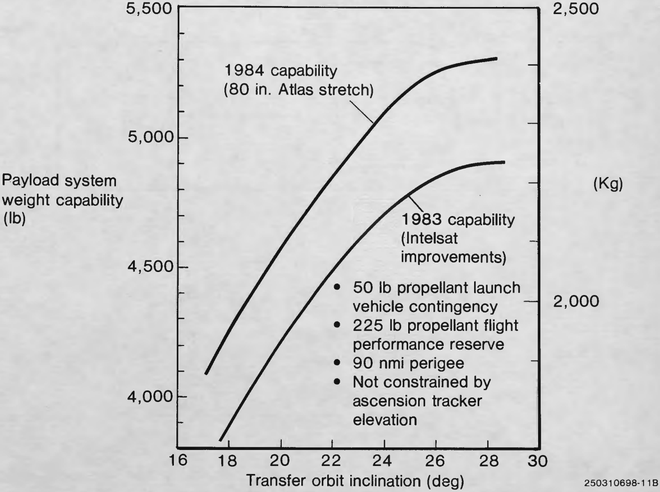


Figure 6. Atlas/Centaur synchronous transfer performance.

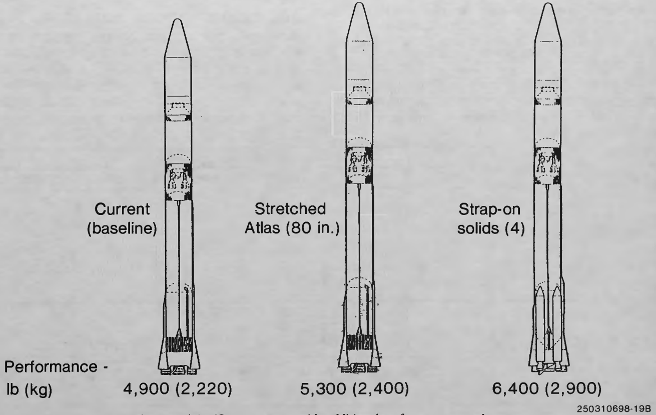
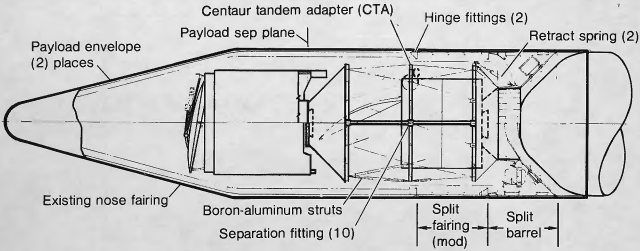


Figure 7. Atlas/Centaur can provide additional performance growth.



	Weight (lb)
Spacecraft A	2,800
Spacecraft B	2,800
Centaur tandem adapter	560
Mission peculiar adapter	65
Total	6,225
Capability — strap on solids	6,400

Figure 8. Dual spacecraft can be flown with Atlas/Centaur capability.

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LAUNCH SCHEDULE

The current firm Atlas/Centaur launches are shown in Figure 9. Three Intelsat V launches, one COMSTAR and one Fleetsatcom launch are scheduled in 1981. COMSTAR 4 was successfully launched on 21 February 1981 with the second Intelsat V as the next scheduled launch in May.

Currently, Intelsat is considering accelerating the production schedule for the three Intelsat V-A vehicles in order to be able to launch them starting in mid-1983, and replacing these vehicles with additional Atlas/Centaurs for launch in 1984.

SHUTTLE/CENTAUR

General Dynamics Convair Division, under a number of separate contracts and company funded activities, has been studying the integration of the Centaur stage into the Space Shuttle since 1971. This activity culminated with a 1979 Centaur-in-Shuttle integration study which defined in detail the modifications to Centaur required for interface compatibility and mission safety.

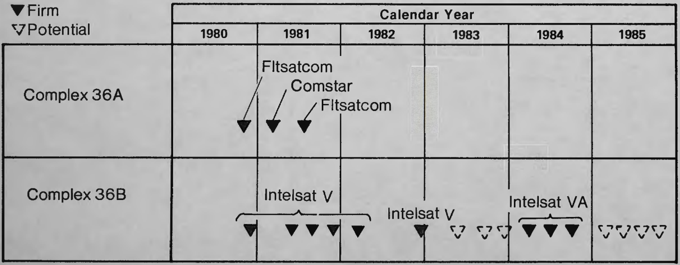

Figure 9. Atlas/Centaur launches are planned through the mid 1980s.

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Shuttle modifications were defined by Rockwell International under the direction of NASA-Johnson Space Center (JSC). The ability to safely integrate Centaur-in-Shuttle was determined by JSC and Kennedy Space Flight (KSC) center personnel during Phase 1 safety reviews. All of these activities concluded that Centaur is ready for Space Shuttle integration (Figure 10).

During the last two months of 1980, NASA conducted a concentrated study of Shuttle upper stages to perform the Galileo and International Solar Polar (ISPM) missions. The conclusion of that analysis was the FY 1981 and 1982 budgeted resources would allow NASA to begin modification of Centaur for integration with the Shuttle so this powerful combination would be available for first launch in 1985. Shuttle/Centaur would satisfy the NASA planetary mission requirements and also be available for future commercial and national security missions. In January 1981, Dr. Frosch made the decision to recommend to Congress and the administration that NASA pursue this course of action.

CENTAUR MODIFICATIONS FOR SHUTTLE

The Centaur stage modifications required for Shuttle compatibility can be separated into two distinct areas: (1) interface compatibility and mission requirements and (2) safety considerations. For interface compatibility, the structural adapters must be modified; fill, drain, and vent systems are changed; a new LH_2 tank insulation blanket is added; and zero-g vent devices are required. Mission requirements dictate a TDRS compatible transponder and may require a star tracker for guidance update to meet mission accuracies if a number of Shuttle orbits are required prior to Centaur deployment.

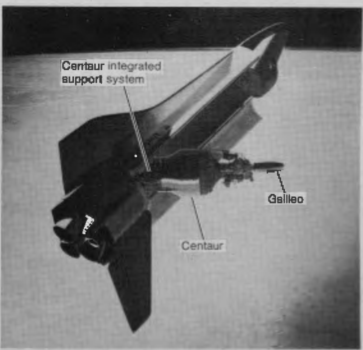
Safety considerations required additional redundant valves and tank pressure transducers for propellant control, a new propellant dump system, reconfiguring of the helium purge system, and a new radio command link to inhibit engine firing after separation from the orbiter should a problem arise. These modifications still leave 95% of Centaur stage components unchanged.

WIDE BODY CENTAUR

The 1979 Centaur-in-Shuttle studies were based on using the current Centaur stage, which is 30 ft in length and 10 ft in diameter, and integrating it directly into the Shuttle. Performance requirements for the 1985 Galileo and ISPM missions dictated a significant increase in propellant weight that would be required to accomplish the missions. Since stretching the current Centaur in length only would result in inefficient use of the cargo bay, it was decided to stretch the LH_2 tank to 170 inches in diameter, thus utilizing the full orbiter bay available and increasing the length available for spacecraft as shown in Figure 11. The LO_2 tank diameter was held constant while a 30-inch cylindrical section was added. Centaur's propulsion system is unchanged; however, the forward equipment module and adapter diameter was increased to match the hydrogen tank diameter.

PERFORMANCE CAPABILITIES

Shuttle/Centaur performance capability significantly expands NASA's capability to perform solar exploration missions. Galileo can be launched in 1985 as a combined orbiter/probe using either a modified Type I trajectory (broken plane) or a Type II trajectory which arrives somewhat later. This is one of the most difficult



- Centaur integration & modifications defined by General Dynamics & NASA LeRC
- Shuttle modifications defined by Rockwell & NASA JSC
- Safe integration determined by NASA Johnson Space Center & Kennedy Space Flight Center

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Figure 10. Centaur is ready for Shuttle integration.

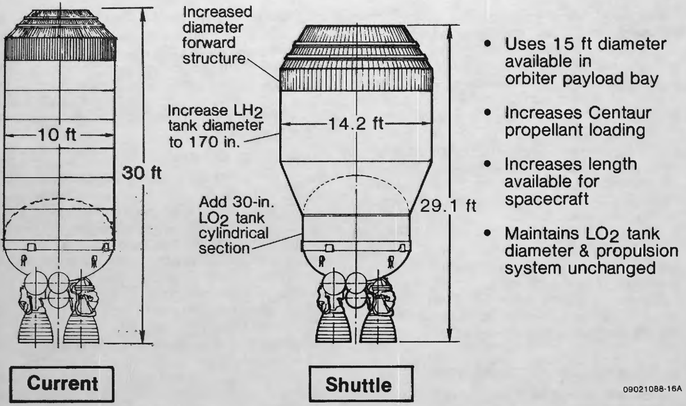

Figure 11. The wide body Centaur is a minimum modification to the current Centaur.

launch years for Galileo and could not be accomplished with any other upper stage, even by launching the orbiter and probe separately (Figure 12).

International Solar Polar can also be launched in 1985 with a single launch for both spacecraft and during the same launch opportunity as Galileo; however, a Star 48 upper stage is required. Future solar exploration missions such as Venus Orbiting Imaging Radar (VOIR), Saturn Orbiter Probe, Uranus Orbiter Probe and Solar Probe will benefit from this improved capability.

Shuttle/Centaur will have a geosynchronous capability of 14,000 lb in orbit with the standard wide body configuration. This is nearly three times the pro-

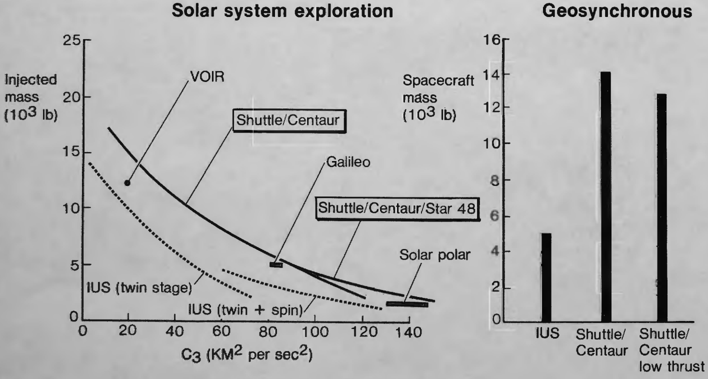

Figure 12. Centaur dramatically enhances Shuttle capability.

jected capability of Shuttle/IUS. For spacecraft with large deployed structures, Centaur engines can be operated in a low thrust mode (83,000 sec test time), which will allow the structures to be deployed and checked out prior to synchronous transfer. The geosynchronous capability for this type of mission exceeds 12,000 lb on orbit.

POTENTIAL MISSIONS

Some of the potential missions that Shuttle/Centaur could launch during the latter part of the 1980s include NASA's solar exploration missions Galileo, ISPM, VOIR, Solar Probe, and either an asteroid mission or comet mission. A geostationary platform demonstration flight, planned for 1987, could use Centaur capability in the low thrust mode. Large commercial communication satellites could also be launched either in single or tandem mode.

SUMMARY

Atlas/Centaur is a flight proven, reliable launch vehicle currently being uprated to deliver 5,300 lb to geosynchronous transfer orbit. Potential uprates include strap-on solid motors that could further increase this capability to 6,400 lb. This would allow launch of dual full-size Delta class spacecraft. Launches for Atlas/Centaur extend into the mid-1980s.

Shuttle/Centaur is ready for integration and now planned for a 1985 launch. Vehicle modifications required are minimal, and the stage has been determined safe by NASA. Geosynchronous orbit capability for this vehicle is 14,000 lb with a potential capability of 12,000 lb for a low thrust mission. Centaur will enhance NASA's solar system exploration capability with missions for this powerful combination extending through 1989 and beyond.